Curved Mirrors

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Introduction

The exact observation of a candle flame in front of an behind a flat mirror teaches a number of fundamental mirror characteristics. Those who use a curvable mirror for the experiment can go even further into the question of real-image formation at a concave mirror.

1 Image formation and geometrical optics

During lessons pupils are usually taught how to construct real images at a concave mirror. To do this, light beams and the law of reflection are employed and size and position of the image are obtained graphically. However, this method does not explain the image appearing at all and also at a specific spot, because geometrical optics neglects the intensity. This very question, however, is of interest during lessons and we will attempt to track down its solution. To achieve this, we would like to observe the following rules.

(a) We introduce, as a physical principle, that the intensity will be higher at those spots which the light can reach on several paths;

(b) this, together with Fermat's law, will then be used to develop the form of a light-collecting concave mirror.

(c) A candle serves as a light source, as it provides a natural light and also, if needed, a point source. Furthermore, it simplifies the proof of the similarity between object and image, for instance by blowing on the flame.

2 The flat mirror

If one puts a candle in front of a flat mirror it is possible to find the position of the mirror image of the candle – the "mirror candle"; looking down on the experimental set-up provides a clear view of the shadow boundaries a and b of the mirror (figure 1). The candle is at the intersection of their reversed-direction extensions (a' and b'). The boundaries of the reflected diverging light beam c and d appear somewhat weaker because they are in an area of higher intensity. Extending them beyond the mirror yields the position of the mirror candle at their intersection.

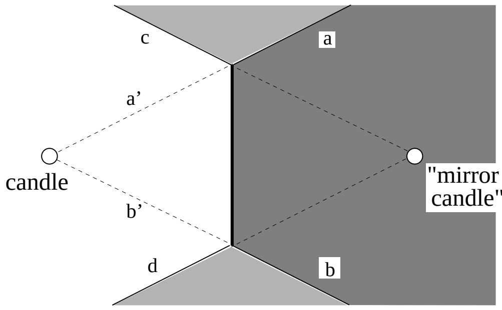

Abbildung 1: Position of the candle and the image at the flat mirror (top view)

3 The curved mirror

The above rule also applies to curved mirrors. The demonstration requires a mirror of pliable Plexiglass (or equivalent material) which is at least as big as a sheet of writing paper (A4). A sheet of Plexiglass such as that bought for decorational purposes will be sufficient. As in the experiment with the flat mirror, no narrow light beams shuld be employed as a ”light ray” for illustration purposes; rather the whole, natural light of the candle shuld be observed. Just as with the flat mirror the curved mirror shows the position of the ”mirror candle” at the intersection of the extended boundaries of the reflected light beam (figure 2).

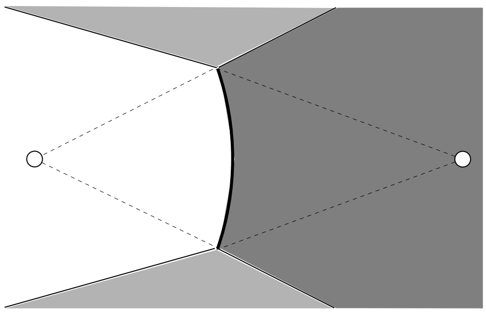

Abbildung 2: Position of the candle and the image at the slightly curved mirror (top view)

With increased curving, the reflected light beam aquires parallel boundaries: the position of the mirror candle is infinitely far away. Even stronger curving causes the boundaries of the reflected light to intersect in front of the mirror. Thus, the ”mirror candle” returns from infinity – but to the candle’s side of the mirror. In this case, the position of the ”mirror candle” is one of particularly increased intensity as many light paths intersect here which extend from the candle to this position via the mirror. This is possible, because all these light paths (or at least their projection onto the observation surface) have equivalent path lengths and consequently the light cannot ”select” the shortest path (respectively the one of least time), as a law which describes the spreading of light – Fermat’s Law – demands. Feynman concludes: ”The only

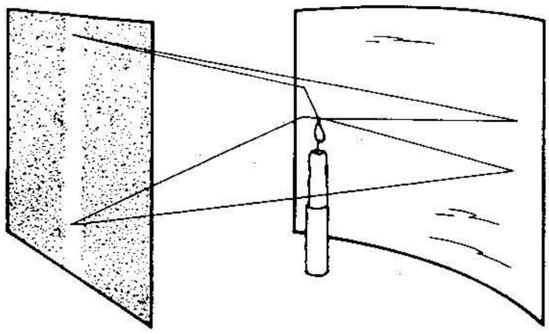

Abbildung 3: A bright line of light appears at the screen

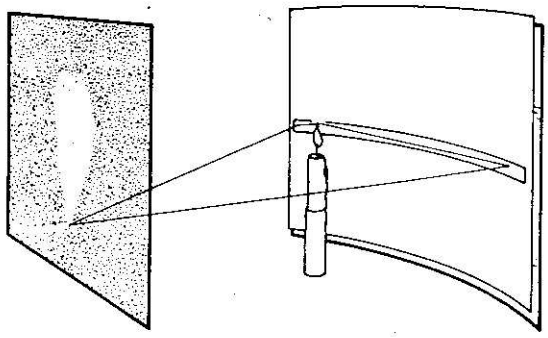

Abbildung 4: Using a screen with a horizontal slit directly in front of the mirror, we are producing a real image of the candle

way that the light can be perfectly satisfied to take several adjacent paths is to make those times equal! Otherwise, it would select one of least time." [FLS65].

4 Image formation

If one places a screen at the position of the light paths' intersection, a bright vertical line of light appears there – and not a point of light or an image of the mirror candle (figure 3). This happens because light paths of equal length are available from the light source to points at any height on the line (namely, via areas of varying height on the mirror). One can now remove most of the light paths so that the light comes to the screen only via a determined height of the mirror, by placing a screen with a horizontal slit directly in front of the mirror and then bending the mirror and this screen together.

One now receives a real image of the candle (figure 4). In this manner, the correct form of an image-forming mirror can be worked out together with pupils. The principle of this mirror also works for a lot of similar problems. To collect the light coming out of one point in another point, we use a mirror made in the shape of a ellipse. The mirror used in the experiment has approximately that form. A paraboloidal mirror gathers the light of sources like the sun or the stars light years away. Even the focussing effect of lenses can be understood, if we know the velocity of the light in the lens medium.

Literatur

[FLS65] Feynman, R. P. ; Leighton, R.B. ; Sands, M.: *The Feynman Lectures on Physics.* Reading : Addison-Wesley, 1965